1. Introduction

Fuji Electric has developed and mass-produced several series of IGBT-IPMs (insulated gate bipolar transistor-intelligent power modules), beginning with the J-series in 1993, followed by the N-series in 1995 and then the R-series in 1997. The J-series realized low loss, the N-series achieves soft switching and the R-series realized high reliability, high cost performance and improved protection accuracy by adopting a protection function to guard against overheating of the chip.

Against the backdrop of recent demands for higher frequency, smaller size, higher efficiency and lower noise requested of power electronics products, Fuji Electric has developed two new intelligent power modules, the R-IPM3, which is based on the R-IPM and provides improved loss characteristics, and the small and thin Econo IPM, which combines concepts of the R-IPM and Econo modules. This paper will introduce both of these modules.

For the IGBT, we developed a NPT (non punch through) microchip (T-series) having a thickness of 100 µm, which was realized by the establishment of a thin wafer process. For the FWD (free wheeling diode), we newly developed a new structure-FWD dies. This new FWD dies has an improved soft-recovery function. Table 1 lists the special features of each IPM series.

We developed three series: the RTB type that has improved cost performance, the Econo IPM that is realized in a small-size and thin package, and the RTA type that has a low loss level. In Fig. 1, external views of the R-IPM3, Econo IPM and small capacity R-IPM3 are shown.

2. R-IPM3 and Econo IPM Series

Table 2 lists the product series, characteristics and internal functions of the R-IPM3 and Econo IPM. IGBT dies adopted a NPT planer structure and attempted to reduce the switching loss. FWD dies optimized the anode structure and further improved the soft-recovery function.

The R-IPM3 series has external dimensions and functions that are interchangeable with the prior R-IPM series, and consequently, it is the most suitable replacement.

The Econo IPM series minimized its external dimensions and decreased its footprint by about 30% compared to the conventional R-IPM. Further, by adding the upper arm alarm output, more reliable protection against a grounding fault can be realized.

For both of these series, we prepared a 6-in-1 module set and a 7-in-1 module set (including a built-in IGBT for braking) with 50 to 150 A of rated current for the 600 V class modules. Further, for 20 A low

Table 1 Special features of IPM

<table>
<thead>
<tr>
<th>Series name</th>
<th>R-IPM3</th>
<th>Econo IPM</th>
<th>Low capacity R-IPM3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Item</td>
<td>RTA</td>
<td>RTB</td>
<td></td>
</tr>
<tr>
<td>External dimensions</td>
<td>Interchangeable with R-IPM series (Standard package)</td>
<td>Small size, thin-type Pin terminal</td>
<td>Package with copper base Small size</td>
</tr>
<tr>
<td>Special feature</td>
<td>Low power dissipation (18 % less than R-IPM)</td>
<td>Low power dissipation (10 % less than R-IPM)</td>
<td>Low power dissipation (10 % less than R-IPM)</td>
</tr>
</tbody>
</table>
capacity elements, we improved the ease of use by using a copper base type package. Consequently, the user can select an appropriate product from a diverse product line-up. Figure 2 shows the external view of each IPM.

### 3. Special Features of the Power Devices

Cross-sectional views of the PT (punch through)-IGBT applied to the prior R-IPM and the NPT-IGBT applied to the R-IPM3 and Econo IPM are shown in Fig. 3.

The three special features of the NPT-IGBT are as follows:

1. The saturation voltage between collector and emitter \( V_{CE(sat)} \) has a positive temperature coefficient, and consequently current does not concentrate in a unit cell in the chip.
2. The temperature dependency of turn-off loss \( E_{off} \) is small.
3. There is no lifetime control, and consequently the fluctuation of \( V_{CE(sat)} \) is small.

The trade-off relation between \( V_{CE(sat)} \) and turn-off loss is shown in Fig. 4. From Fig. 4, it can be seen that the prior IGBT chip’s N-series and S-series have a high temperature dependence. On the other hand, the newly developed NPT planer chip mounted T-series has low temperature dependence, and therefore can reduce the turn-off loss at high temperatures.

Figure 5 compares the fluctuation of \( V_{CE(sat)} \)
**Fig. 2**  External dimensions of IPM

<table>
<thead>
<tr>
<th>Series name</th>
<th>R-IPM3</th>
<th>Econo IPM</th>
</tr>
</thead>
<tbody>
<tr>
<td>Package type</td>
<td>P610, P611</td>
<td>P619, P622</td>
</tr>
<tr>
<td>Outline drawings</td>
<td><img src="image1" alt="Outline drawing" /></td>
<td><img src="image2" alt="Outline drawing" /></td>
</tr>
<tr>
<td>Dimensions</td>
<td>L109×W86×H22 (mm)</td>
<td>L70×W46.5×H9.5 (mm)</td>
</tr>
<tr>
<td>Mass</td>
<td>450g</td>
<td>85g</td>
</tr>
</tbody>
</table>

**Fig. 3**  Comparison of IGBT chip cross-sections

- **NPT-IGBT**
  - Emitter
  - Gate
  - Collector
  - Thickness: 100 µm

- **PT-IGBT**
  - Emitter
  - Gate
  - Collector
  - Thickness: 70 µm
  - Thickness: 350 µm

**Fig. 4**  Trade-off curve of IGBT chips

- **S-series (PT planer)**
- **T-series (N-series)**
- **N-series (R-series)**

**Fig. 5**  Distribution chart of $V_{CE\text{(sat)}}$

**Comparison of fluctuation**

<table>
<thead>
<tr>
<th>$V_{CE\text{(sat)}}$ (V)</th>
<th>0.5</th>
<th>1.0</th>
<th>1.5</th>
<th>2.0</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of chips</td>
<td>3</td>
<td>2</td>
<td>1</td>
<td>0</td>
</tr>
</tbody>
</table>

**Fig. 6**  Comparison of recovery switching waveform of FWD between conventional FWD and new FWD

- **Conventional FWD**
  - $V_f$: 50 V/div
  - $I_f$: 25 A/div
  - $dv/dt$: 9.8 kV/µs
  - $t$: 50 ns/div

- **New FWD**
  - $V_f$: 50 V/div
  - $I_f$: 25 A/div
  - $dv/dt$: 6.8 kV/µs
  - $t$: 50 ns/div

**Between the PT-planer chip and the NPT-planer chip, $V_{CE\text{(sat)}}$ of the NPT-planer chip is distributed in a limited range and exhibits stable, steady-state loss.**
characteristics.

Next, we shall describe the FWD that has been utilized in the R-IPM3 and Econo IPM. Fuji Electric applied the new structure to the FWD in order to decrease emission noise. Figure 6 shows comparison of recovery switching waveform of FWD between conventional FWD and new FWD. New structure FWD achieves, that suppress the injection of holes from the anode and decrease the reverse recovery peak current to achieve soft recovery.

4. Package Construction

In order to achieve smaller and thinner dimensions, the Econo IPM is manufactured with a different construction than the prior IPM. In the prior package, a terminal bar was used for the interconnects. But with that method, the height of package cannot be decreased because of the limitations of the bar interconnects. For this reason, the Econo IPM changed from a terminal bar construction to a method of using

Fig.8 Example of Econo IPM installation

Fig.9 Comparison of total loss

Fig.10 Turn-off waveform

Fig.11 Comparison of the spectrum of emission noise
aluminum wires for all internal interconnects. Further, to limit the package width, we introduced a construction wherein the control card printed circuit board is positioned on the second level. By adopting these changes, we succeeded in manufacturing a very compact package (see Fig. 7).

Figure 8 shows an example of an Econo IPM installed in a side-fin type servo-amp. The Econo-DiM (Econo Diode Module) in this drawing was developed with the same concept (the Econo-module concept) as the Econo IPM, and therefore has the same height of 17 mm as the Econo IPM. Since the Econo IPM and Econo-DiM have the same height, they can be connected on the same printed circuit board. By utilizing these two modules, simplification of the design of printed circuit boards can be expected. Further, in order to utilize the thin package more effectively, the Econo IPM reduces the height of a part of its lid. By ensuring a 3 mm space between the printed circuit board and the Econo IPM lid, the mounting of electronics components such as a photo-coupler on the back of the printed circuit board is possible. Consequently, it is expected that dead space in customers’ equipment can be decreased, further contributing to reducing the footprint customer’s equipment.

5. Reduction of Loss

As product development concepts, the reduction of loss and the level of emission noise, which have a mutual tradeoff relationship, are the most important items.

These items were one of the important themes of the newly developed Econo IPM and R-IPM3 modules. During development, we were able to decrease IGBT loss by adopting the newly developed NPT-IGBT, and moreover, by installing a new diode that has a soft-recovery function and by optimizing the driving conditions, we succeeded in realizing the same or lower noise level than the prior R-IPM.

Figure 9 compares total loss between the newly developed Econo IPM, R-IPM3 and the prior R-IPM. As a result of installing the new IGBT chip and FWD chip, loss decreases of 15% in the Econo IPM and 18% in the R-IPM3, compared to the prior R-IPM, were realized. In particular, the decrease in turn-off loss greatly contributed to the decrease in total loss. Figure 10 shows turn-off waveforms of the prior IPM and Econo IPM. Figure 11 shows the emission noise spectrum of the R-IPM and Econo IPM. The emission noise spectrum was measured by the 3 m method for accelerating and decelerating operation utilizing a servo-amp with a 4 kHz carrier frequency. Consequently, it was learned that the noise level is kept at the same level as the prior type over the frequency range from 30 to 130 MHz.
6. Block Diagram of IPM

Figure 12 shows block diagrams of modules with built-in dynamic brake functions. Figure 12(a) is the R-IPM3, and 12(b) is the Econo IPM. In case of Econo IPM, the alarm signal of the upper arm circuit is output externally.

7. Conclusion

IGBT-IPMs which incorporate the latest power device technology from Fuji Electric have been presented. We are convinced that these IPMs will enable the development of highly efficient and small size power electronics application products and will satisfy the market expectations.

We at Fuji Electric will continue to develop and produce new products in order to meet the requirements of markets in the future.

References

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